Monitoring Arctic Ice Movements with Satellite Doppler

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1. INTRODUCTION. The application of doppler satellite technology to ice-movement studies requiring high-quality positional determination ($\pm$ 1 m) has proved of great value in remote areas of Canada. Potential oil and gas anomalies in the Arctic Islands, hundreds of kilometres from land, can now be successfully monitored with regard to ice-floe movement by remote methods on an almost daily basis. Extensive field tests conducted in the Calgary area during the fall of 1976 showed that daily movements as small as 1 m could be detected with high-quality satellite receivers using rigorous three-dimensional multi-station computer processing methods. During the test five JMR-1 receivers were deployed in a cross-like configuration; one receiver was held stationary while the antennae on the other four units were moved 1 m a day forwards and backwards in relation to predetermined baseline stations. Various patterns of movement were introduced to observe the effect on data processing. It became evident during these tests that the technique could offer reliable position-determination for drilling operations conducted through the ice on an almost daily basis.

During the 1976–7 drilling season several satellite receivers were deployed at offshore rig sites and while drilling was in progress these were successfully used to monitor ice movement in the order of one metre. Classical methods were used to check the validity of the results obtained by the doppler-satellite technique. On several occasions tellurometers and theodolites were used and sea-bottom transducers were also employed to study ice movements. During the analysis of all the methods employed it was found that the doppler-satellite technique offered considerable advantages from a logistic viewpoint over other conventional methods. It was also demonstrated that the required accuracy could be achieved by available doppler-satellite processing techniques. The success of these small-scale programmes resulted in the development of a remote data acquisition system.

2. THE REMOTE-DATA-ACQUISITION SYSTEM. During the summer

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of 1977 and prior to the Arctic winter, agreement was reached between Panarctic Oils Limited, a major oil and gas operator in the Arctic Islands, and Shell Canada Resources Limited whereby Shell would provide the equipment, services and processing in monitoring ice movements on some fourteen locations (see Fig. 1). The prime difference in this large-scale operation lay in the area covered by the unmanned data-acquisition systems, deployed in total darkness and severe cold and with only limited station visits between December 1977 and June 1978.

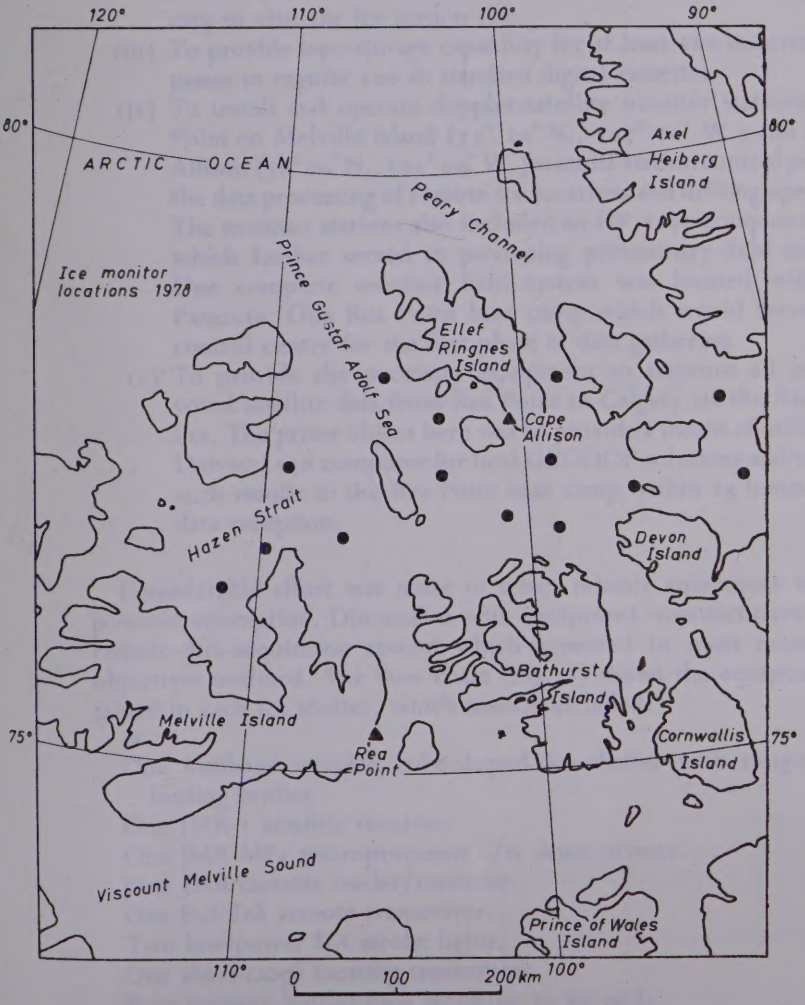

Fig. 1. Ice stations (●) and control points (▲)

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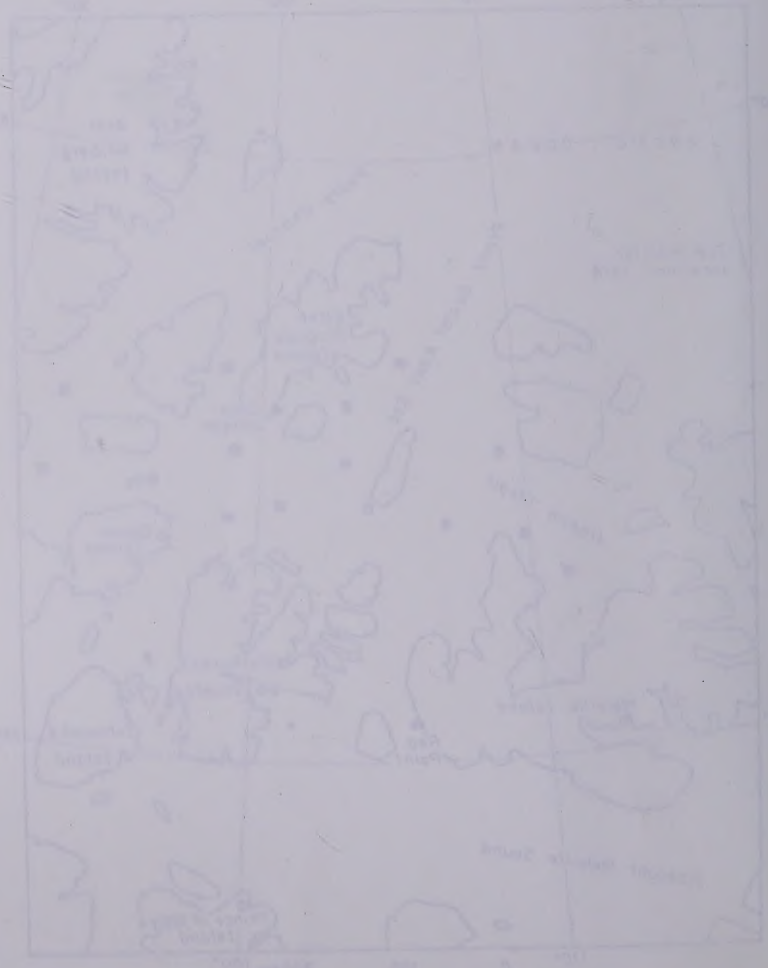


The operational objectives were:

(i) To design, install and operate fourteen unmanned ice stations which could operate unattended for several months and collect sufficient broadcast ephemeris data each day so that, when processed simultaneously with a fixed station, the relative accuracy would produce a position fix to a (1σ) accuracy of 1 m.

(ii) To develop a remote-data-acquisition system whereby these stations would transmit the last twenty passes to a helicopter or aircraft (within 100 km) in the vicinity without it being necescary to visit the ice station site.

(iii) To provide tape-storage capability for at least 660 majority-voted passes in regular 100 m standard digital cassettes.

(iv) To install and operate doppler-satellite monitor stations at Rea Point on Melville Island (75° 20′ N., 105° 00′ W.) and at Cape Allison (78° 00′ N., 101° 00′ W.) as multi-station control points for the data processing of remote ice locations and drilling operations. The monitor stations also included an HP 2100 computer system which further served in producing preliminary field solutions. One complete monitor field system was located within the Panarctic Oils Rea Point base camp which would serve as the control centre for the first phase of data gathering.

(v) To provide the necessary equipment to transmit all majority-voted satellite data from Rea Point to Calgary via the Anik satellite. The prime object here was to provide a means of utilizing the Univac-1140 computer for final GEODOP solutions and to return such results to the Rea Point base camp within 24 hours of field data reception.

Considerable effort was made to select reliable equipment with low power-consumption. Discussions with equipment manufacturers led to a remote-data-acquisition system which appeared to meet most of the objectives outlined. The flow chart (Fig. 2) shows the equipment contained in each ice shelter, which usually included:

One insulated wooden cube-shaped ice shelter with sling-mounted loading bridles.
One JMR-1 satellite receiver.
One JMR-MP4 microprocessor c/w drum printer.
One JMR cassette reader/recorder.
One Ref-Tek remote transceiver.
Two low-power ¾-A strobe lights.
One short-range locating transmitter.
Four propane bottles each weighing 50 kg each.
Two 24-W Global thermoelectric generators.
Four 12-V batteries.

The total weight of the above equipment, including the shelter, is approximately 1000 kg. It is normal to install all equipment and then sling the complete ice station by helicopter to its chosen destination for the winter; an aluminium cylinder is often placed round the shelter to improve its aerodynamic characteristics at high air-speeds.

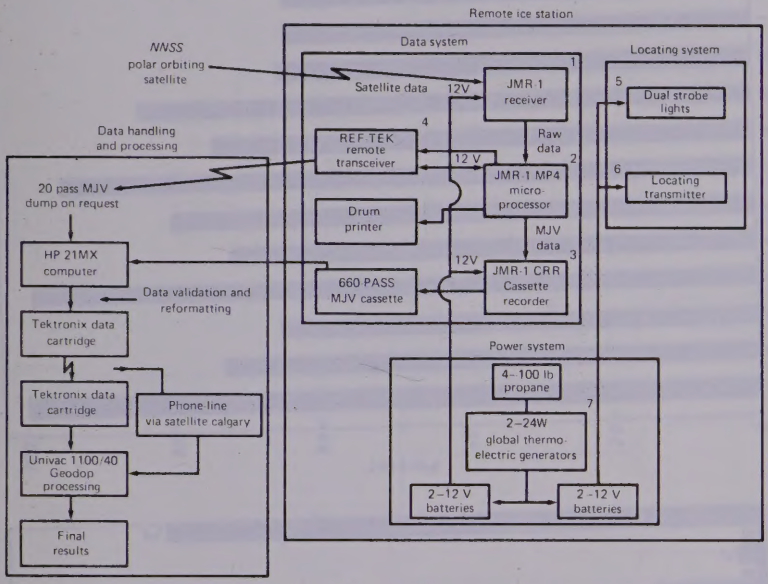


Fig. 2. Remote-data-acquisition system

3. SPECIAL EQUIPMENT FEATURES. In any remote data-acquisition system it becomes necessary to interface equipment from various manufacturers; to establish a smooth data-flow a complete ice-station system was mobilized for three months in the Calgary area prior to the proposed programme. This test programme served to eliminate many of the weak points in the system. It will be seen from the equipment-function description that each item is required to carry out a specific duty.

JMR-1. This receives broadcast ephemeris data from polar orbiting satellites (Transit) and dumps to a JMR-1 M4 microprocessor.

JMR-1-MP4. This microprocessor contains the controlling module of RDAS, accepts raw data from the satellite receiver and dumps compacted majority-voted data to the cassette reader. It has a buffer which stores the twenty most recent satellite passes for transmission through a Ref-Tek remote transceiver.

JMR-1 CRR. This records MJV data from MP4 and stores up to a maximum of 660 passes. It also reads 'alert' tapes.

Ref-Tek. Upon command from the master transceiver, the remote transceiver activates MP4 to dump the contents of the 20-pass storage buffer and transmits data at a frequency of 162 MHz.

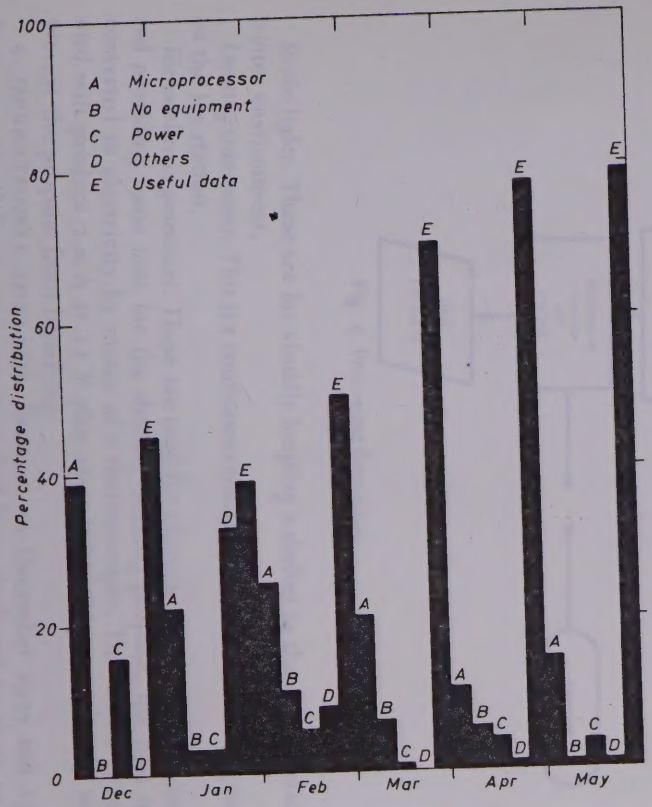


Fig. 3. Operational malfunction analysis

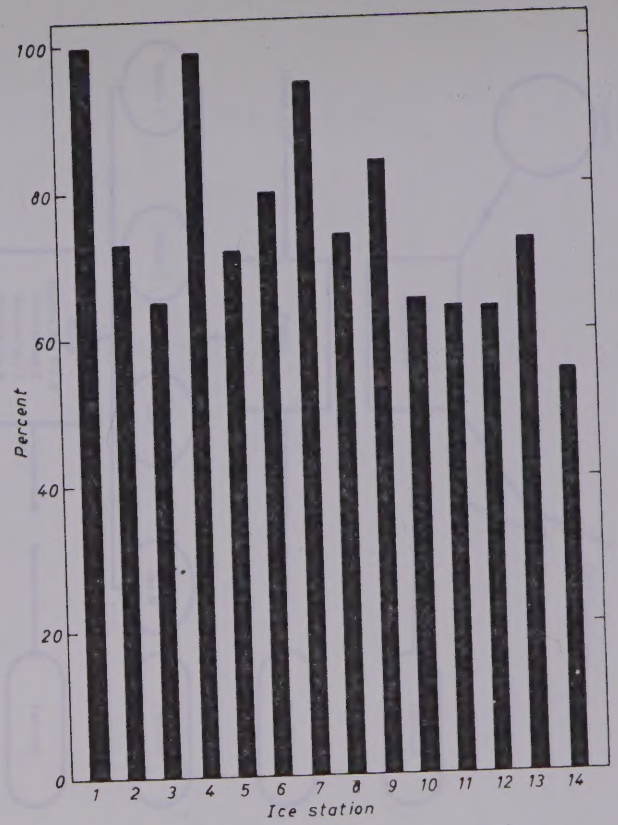
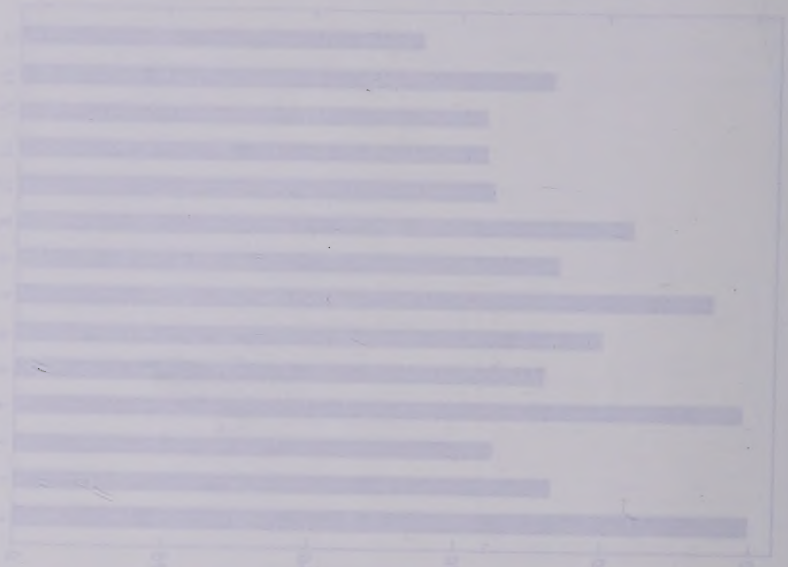
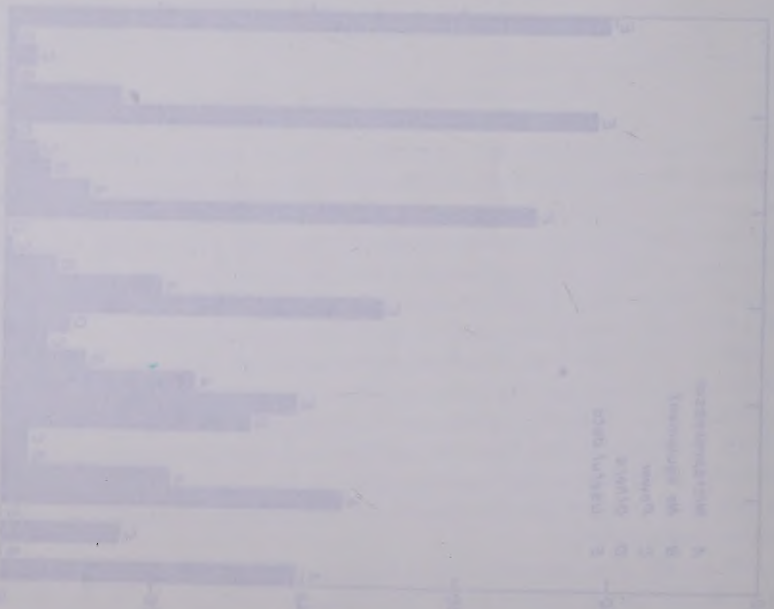


Fig. 4. Percentage of data days at ice stations





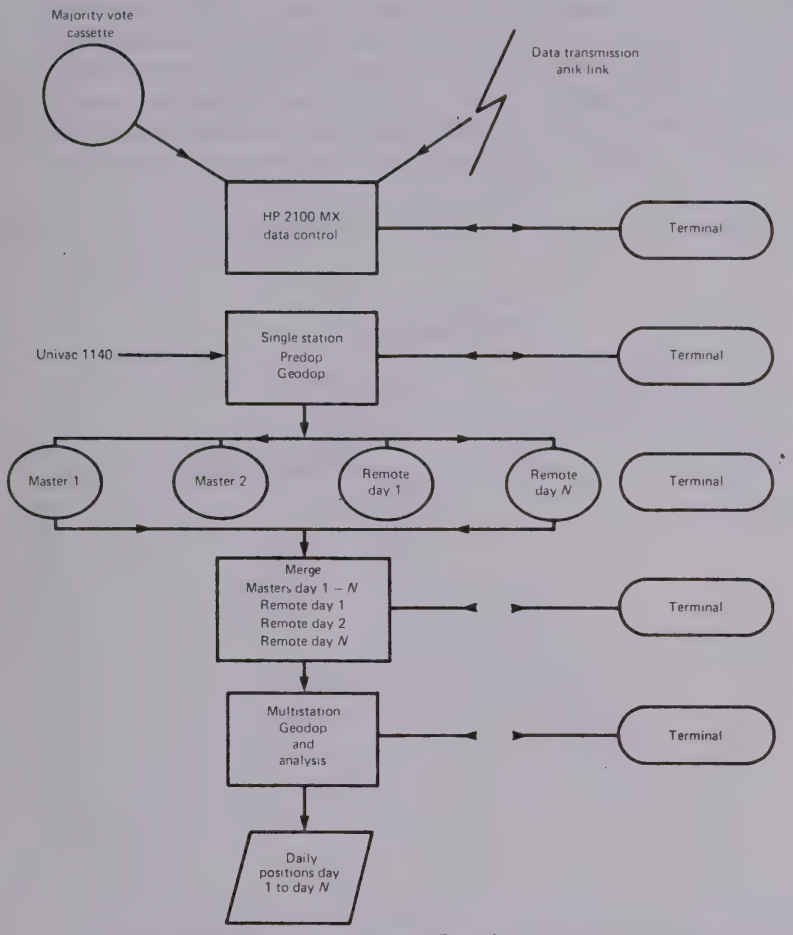


Fig. 5. Processing flow-chart

Strobe lights. These are for visually locating a shelter in the dark Arctic winter environment.

Locating transmitter. This is a continuous transmission used for homing-in on the ice station.

Thermoelectric generators. These are used for charging the 12-V batteries and providing some heat for the shelter. Burning propane, the heat is converted to electricity by means of a thermocouple. The Model-5030 used will produce 2.0 A at 12 V plus 1800 BTU of heat, necessary to prevent the propane from liquefying.

4. OPERATIONAL ANALYSIS. Between 10 December 1977 and 25 January 1978 all fourteen ice stations had been deployed to their respective locations. Apart from the difficulties encountered in assembling

the remote-data-acquisition systems under extreme temperatures and in total darkness, no major problems were encountered. The task of gathering and processing the collected data then became the highest priority and it soon became evident that we would encounter data-gathering disruptions as a result of unexpected equipment failures. During the next five months our personnel were kept busy isolating equipment problems and

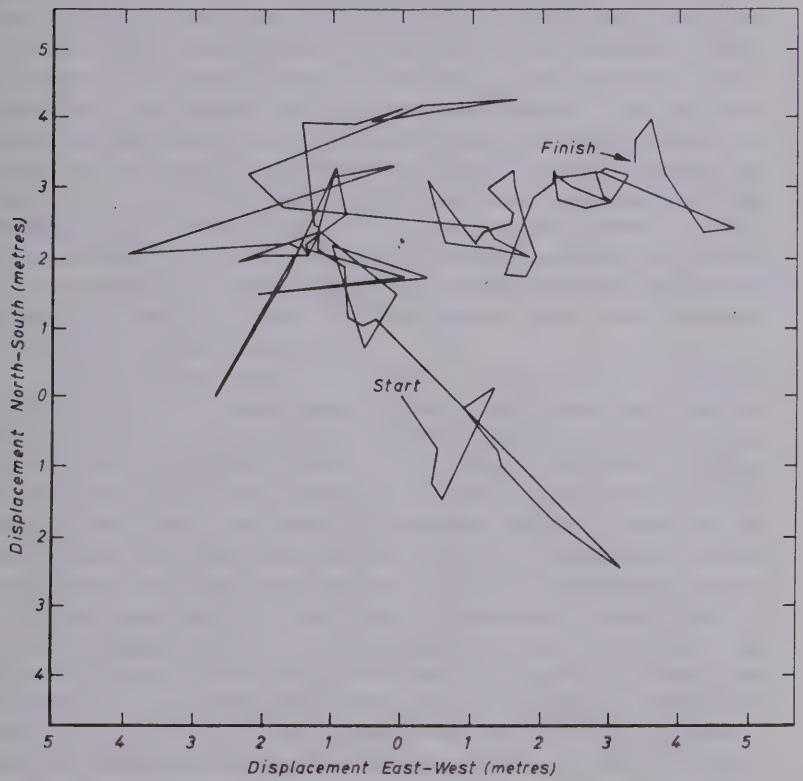


Fig. 6. Daily movement plot for a typical ice station

taking the necessary action. It will be seen from Fig. 3 that the microprocessor, which is the heart of the system, caused us considerable concern in the first three months of operation. Four major modifications were made to the RDAS system in an attempt to cure certain failure patterns that had been identified.

With these modifications the data gathered increased from 50 to 78 per cent, while the microprocessor failure-rate decreased from 25 to 11 per cent. The noticeable increase in data gathered during the last half of the project (March/April/May) stems from field-procedure adjustments that significantly reduced equipment failure rates on the overall project.

Fig. 4 shows the percentage of days with data collected. It will be seen that the last half of the operation was a vast improvement on the initial phase. It was gratifying to note that a number of stations operated almost continuously throughout the five-month period, which showed that the concept was indeed capable of meeting most of the objectives initially defined.

5. DATA PROCESSING. Due to the large number of usable satellite passes available (40–50 per day) in high latitudes it was decided to program the receivers for about 20–25 passes per day. The forced reduction in collected data would conserve power yet provide sufficient data to determine a daily position, based on 20 passes, to an accuracy of 1 m.

Data from the fourteen remote ice stations were of a majority-vote format, pre-processed by the JMR microprocessor and recorded on a cassette reader/recorder, transcribed on the HP 21MX computer and dumped to a tektronix data cartridge. All data were then read from data cartridges to disc files on the Univac 1010–40 computer system in Calgary. A data transmission link via Anik satellite allowed us to send digital data from Rea Point base-camp to Calgary, where final positional results were required on a near daily basis. The data cassettes were usually taken to Calgary during regular crew changes.

6. GEODOP PROCESSING. It will be seen from Fig. 5 that all satellite data follow a distinct pattern, from majority-vote reception to a final daily position determination. The daily position of each ice station was determined by holding Master 1 (Rea Point) and Master 2 (Cape Allison) fixed on previously determined positions. This procedure was continued until mid-April, when the monitor at Cape Allison was dismantled; thereafter Rea Point was the only station held fixed. All data were precessed by using the full series of GEODOP computer programs.

The final latitude and longitude of each day-solution, obtained from the GDLSAT program, were then converted to UTM coordinates and movements from the initial day of observation computed. The transverse mercator coordinates were used to plot ice movements using a WANG-600 series desk computer. Position reports for each day were then completed, along with updated plots for the fourteen ice stations. The daily movements for one such station is shown in Fig. 6,

7. DATA EVALUATION AND RESULTS. It was generally possible to derive positions using the multi-station solution process to an accuracy (1σ) of 1 m after twenty passes. The ice-station receiver, however, often has some small displacement during the grouping of these passes; this has the effect of slowing down the convergence towards position determination. For example, it has been shown that a doppler count can be measured with reliability to about 0·17 m, but under the operational conditions of this project it was necessary to adopt a limit of 0·34 m to avoid a high rejection rate for passes. It was also noted that high Sunspot activity around 30 January 1978 influenced data-rejection parameters; after 10 April this particular phenomenon seemed to disappear

TABLE 1. ICE-STATION MOVEMENT SAMPLE

Station	Lat.			Long.			HT	Radial movement (m)	Standard Deviations (m) (1σ)		
	°	′	″	°	′	″			Lat.	Long.	Ht
REA	75	21	37·17	105	43	28·10	22·3	—	0·00	0·00	0·00
ALL1	77	49	42·16	100	17	22·75	16·7	—	0·00	0·00	0·00
R025	76	42	55·69	109	46	31·63	4·6	0·2	0·20	0·23	0·21
R026	76	42	56·68	109	46	31·63	4·8	0·4	0·19	0·21	0·20
R029	76	42	56·68	109	46	31·72	5·6	0·8	0·33	0·34	0·37
R031	76	42	56·69	109	46	31·64	4·4	0·1	0·47	0·53	0·50
R032	76	42	56·69	109	46	31·66	4·4	0·2	0·32	0·36	0·35
R033	76	42	56·69	109	46	31·69	4·6	0·5	0·32	0·35	0·33
R034	76	42	56·68	109	46	31·70	5·1	0·8	0·38	0·40	0·37
R035	76	42	56·69	109	46	31·71	5·2	0·5	0·35	0·39	0·34
R036	76	42	56·71	109	46	31·78	5·6	1·0	0·30	0·36	0·30
R037	76	42	56·75	109	46	32·09	5·2	3·6	0·41	0·51	0·42
R038	76	42	56·74	109	46	32·13	5·7	3·6	0·43	0·50	0·49
R039	76	42	56·71	109	46	32·00	6·3	2·5	0·51	0·62	0·50
R040	76	42	56·72	109	46	31·82	6·3	1·3	0·53	0·61	0·54
R041	76	42	56·74	109	46	31·75	6·1	1·8	0·52	0·51	0·50
R042	76	42	56·75	109	46	31·75	6·2	1·7	0·48	0·53	0·52

and doppler-count acceptance rates returned to a high level. These adverse factors effected the amount of data gathered, but the positions themselves, when related to the fixed coordinates at Rea Point, were of a high quality. In almost all cases, throughout the entire project, first-order results were attained at all ice stations.

In spite of some data loss, the amount gathered and processed during this project seems difficult to comprehend. A total of 31 300 passes were processed to final position, resulting in some 1100 positions at the ice stations. These figures do not include the 5600 passes observed at Rea Point and Cape Allison, processed a minimum of fourteen times during the project and sixteen times while the drill rigs were in operation.

As previously stated, apart from establishing a history of the types of movement that can be encountered from year to year, it was also necessary to provide daily movements to the drilling superintendents for two drilling operations under way during the period. Because it was necessary to have near real-time positions and these drilling sites were manned, the data were processed with top priority in order to alert the drilling operations of the nature and magnitude of ice movement. Table 1 shows a GDLSAT Summary of movements occuring at one drill site between day 25 and day 42.

8. CONCLUSIONS. The application of doppler-satellite has become a powerful tool in the study of ice pattern behaviour and the remote data-acquisition developed lends itself extremely well where large amounts of data are collected on a seasonal basis. Equipment specifications were often stretched to the absolute limit during the project described and further attention must be given in the design of hardware that can remain stable and reliable under adverse conditions. Some very useful correlations associated with ice movement determinations in the Arctic Islands include:

(i) Gross movements, as on day 36, due to a minor earth tremor in the Arctic Islands, are clearly visible on many of the position plots. The ability of the system to detect the exact time of such movement is a most useful feature in the monitoring of drilling rig locations.

(ii) As a history of ice movement becomes available through several seasons of observation, general trends will be revealed that will be useful in the selection of future drilling sites.

(iii) The period of least ice movements can be determined with confidence during each season. In addition, the approximate time of spring break-up will be recorded each year.

(iv) The effects of wind velocity on ice movement are also being integrated more fully this year by including weather stations.

(v) A better prediction of the magnitude of movements that can be expected in partially land-locked ice areas will eventually be possible.

In summary, considerable improvement should be possible in the volume of data collected by a slight increase in power availability at each ice station. In addition, modifications to the microprocessor should further improve the organizing of data at ice stations, The GEODOP series of programs has recently been made available on a Hewlett Packard 21MX computer with extended core or memory. This software package (Sheltech 791) will enable a faster processing of raw data for final results.

The author is grateful for the co-operation of Panarctic Oils Limited in presenting results and material, largely gathered during contractual commitments, and wishes to thank all those who through their determination and perserverence made this project a reality.

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